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(54) **METHODS, SYSTEMS, AND APPARATUS FOR CALIBRATION OF A POSITIONAL OFFSET BETWEEN AN END EFFECTOR AND A POSITION SENSOR**

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See application file for complete search history.

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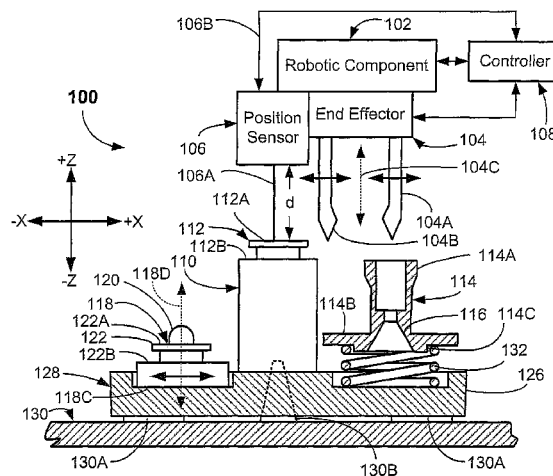
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(57) **ABSTRACT**

Disclosed are systems and apparatus adapted to aid in calibration of an offset position—between a position sensor and an end effector in a processing system. The system includes a robotic component having an end effector and a position sensor coupled thereto, a teach target having a first geometrical feature, and an offset tool adapted to be engaged by the end effector, the offset tool including a first docking feature. The system further includes a moveable offset target having a second docking feature adapted to be engaged by the first docking feature and a second geometrical feature adapted to be sensed by the position sensor. The end effector moves the offset tool to the offset target and docks them. A position of the teach target and the offset target may then be sensed with the position sensor to determine an actual offset of the end effector with respect to the position sensor. Methods of operating the system are provided, as are other aspects.

**8 Claims, 13 Drawing Sheets**



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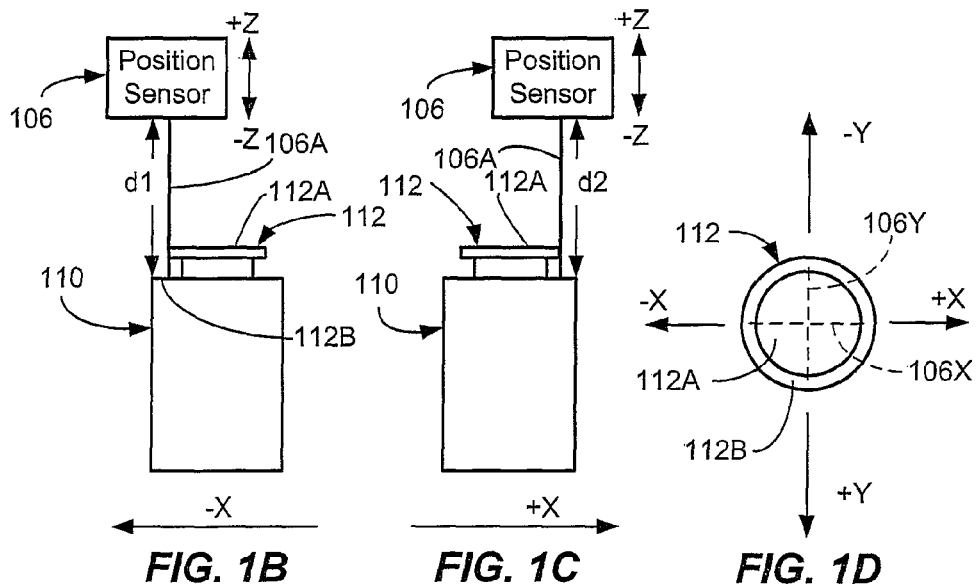
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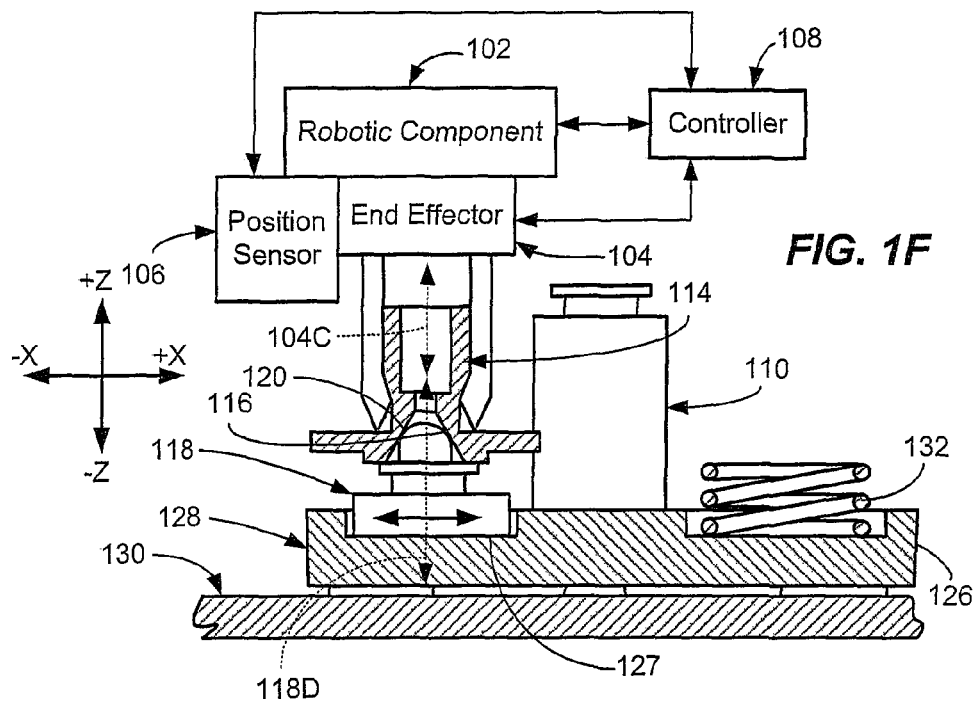
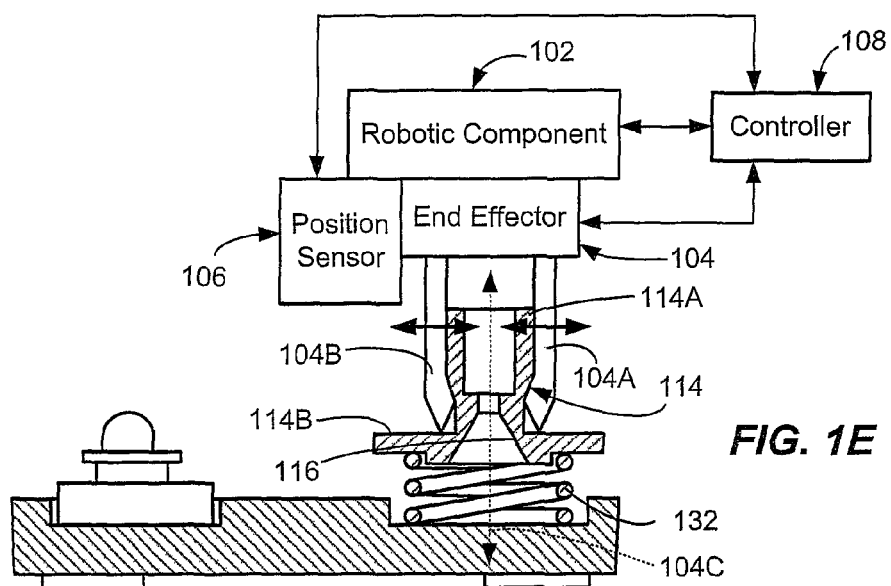
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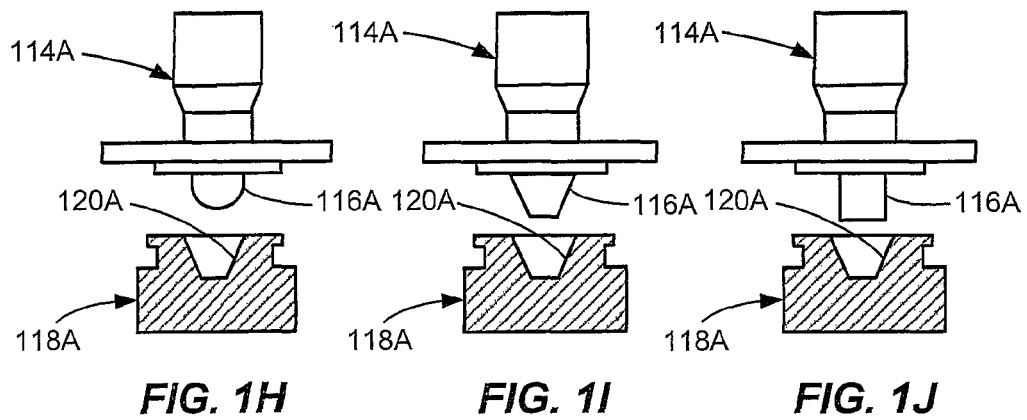
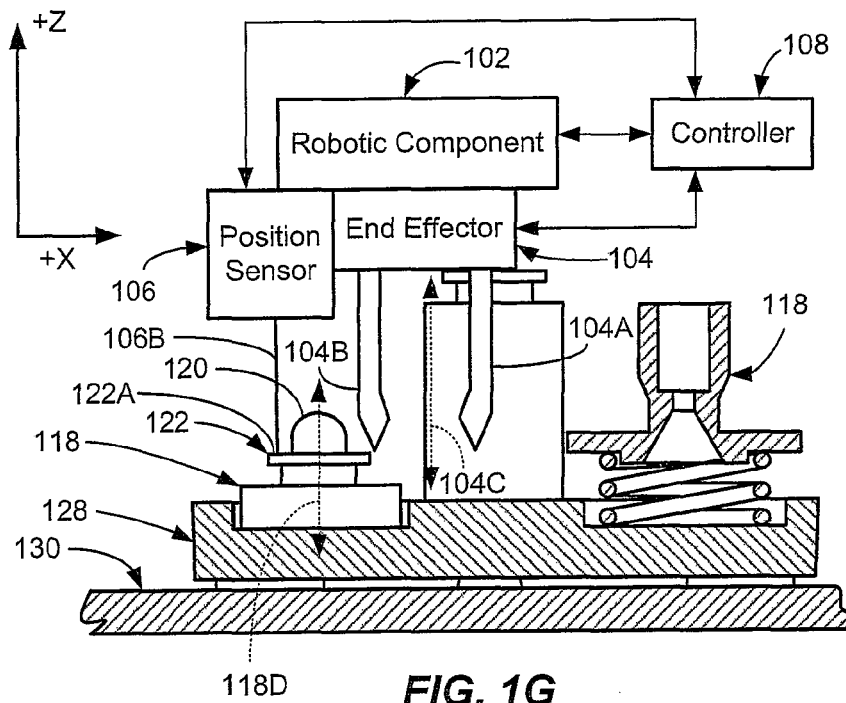
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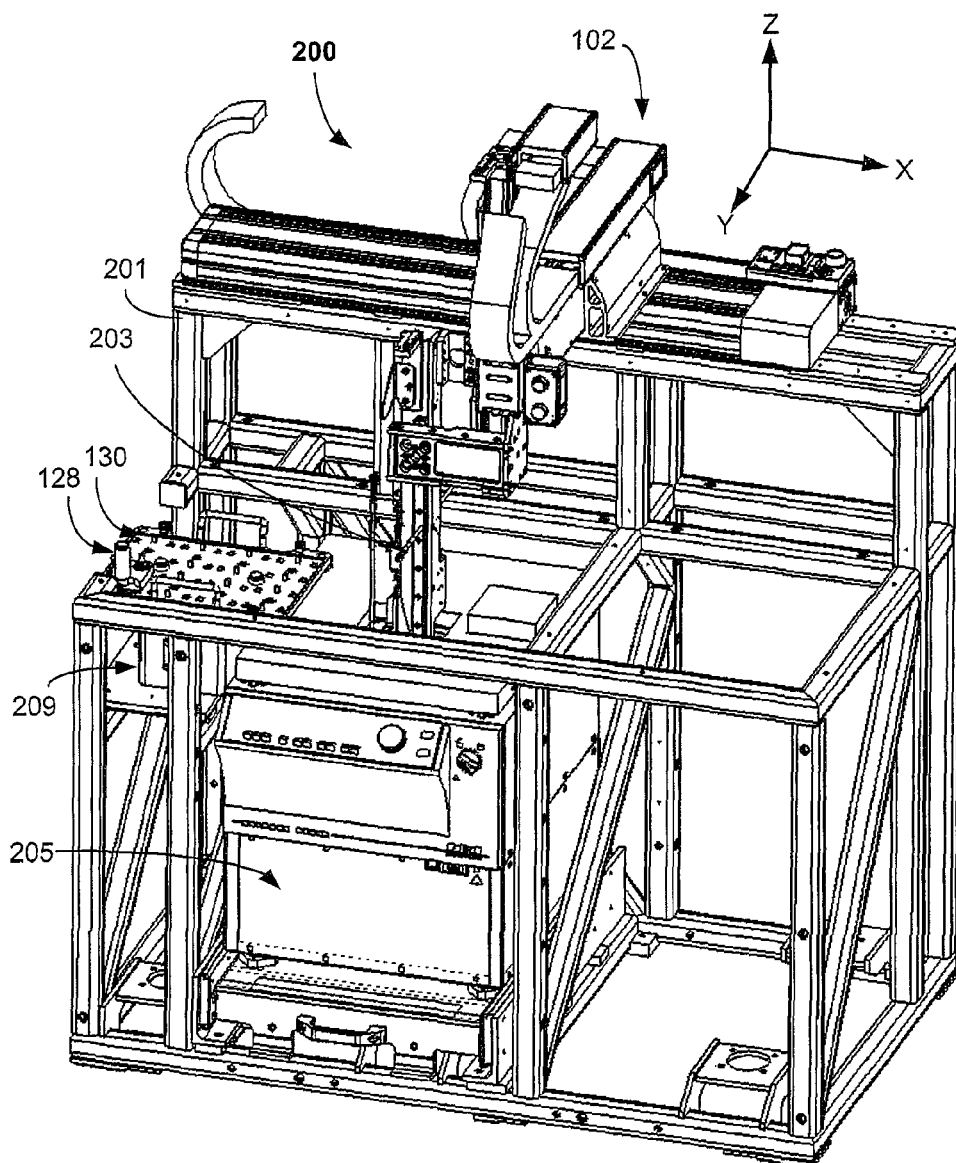


FIG. 2A

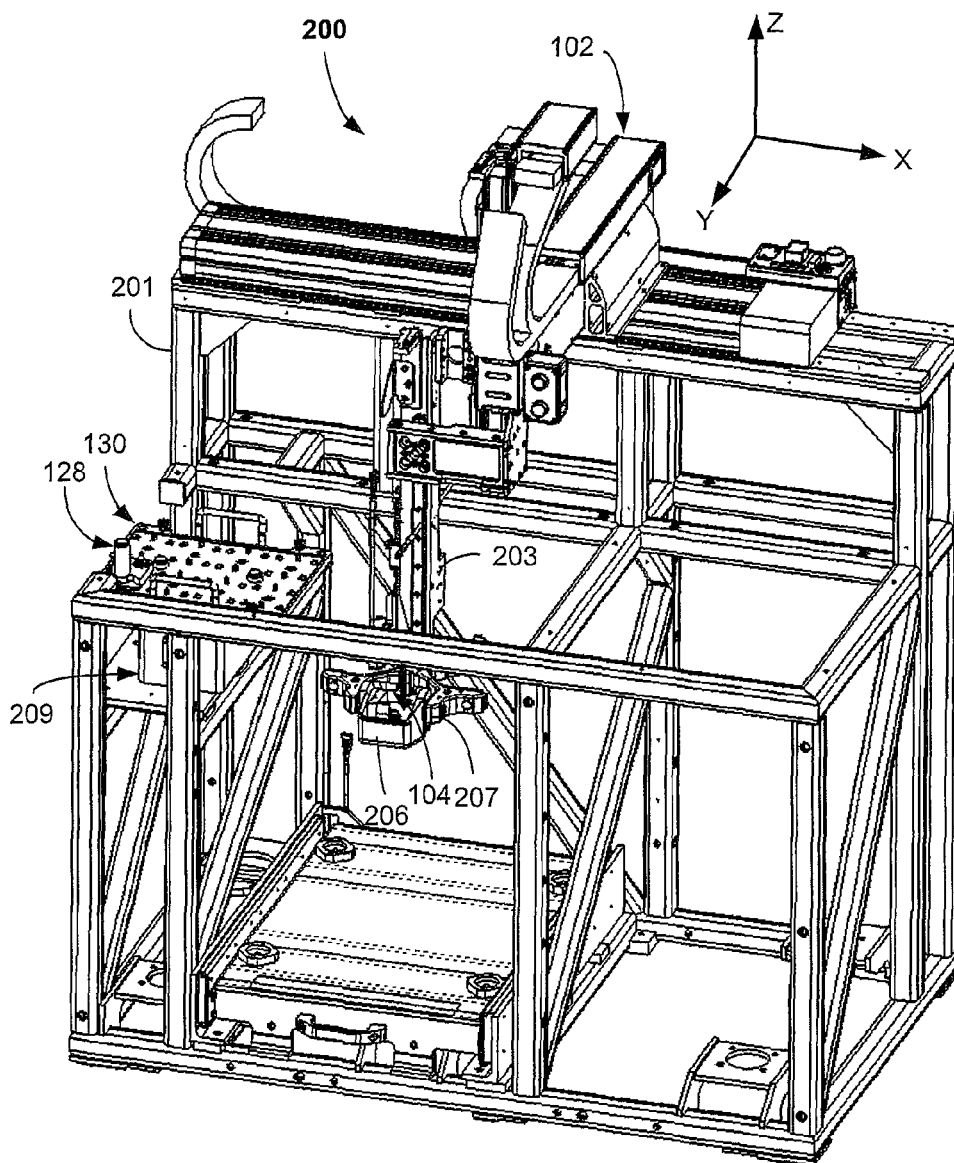


FIG. 2B

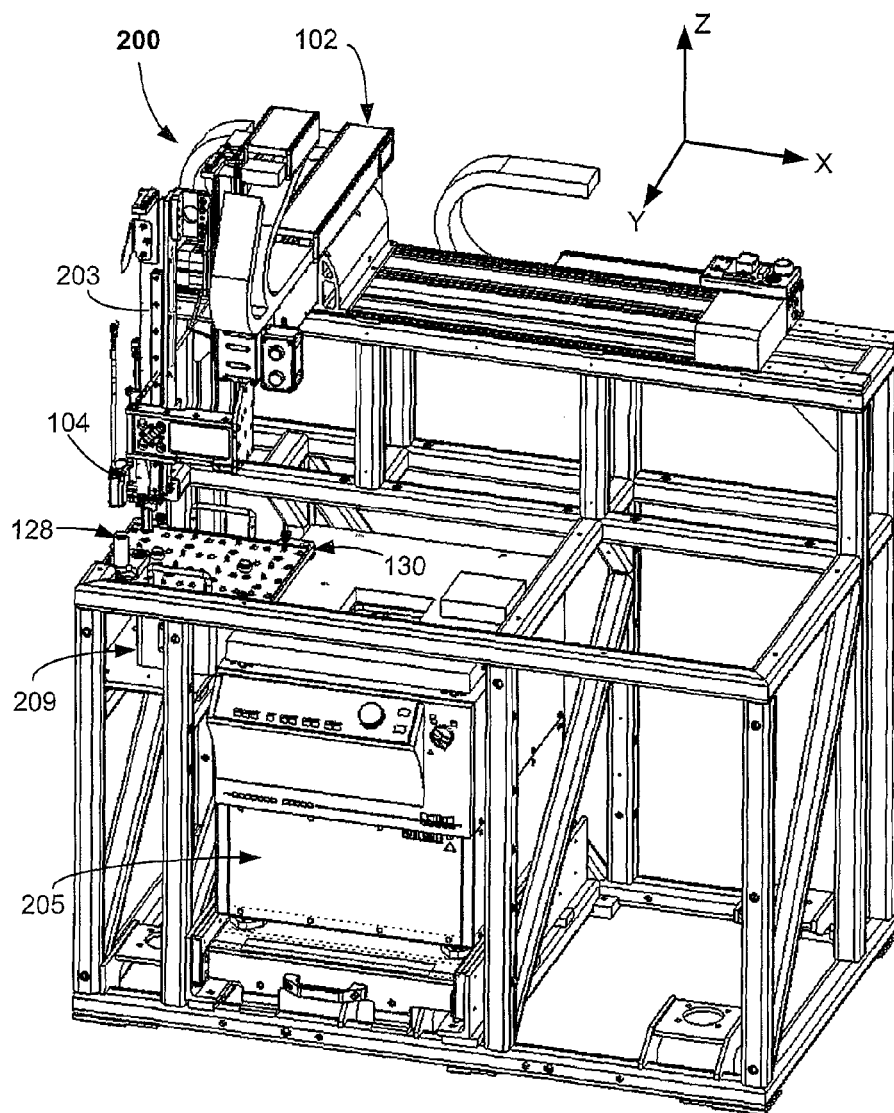


FIG. 2C



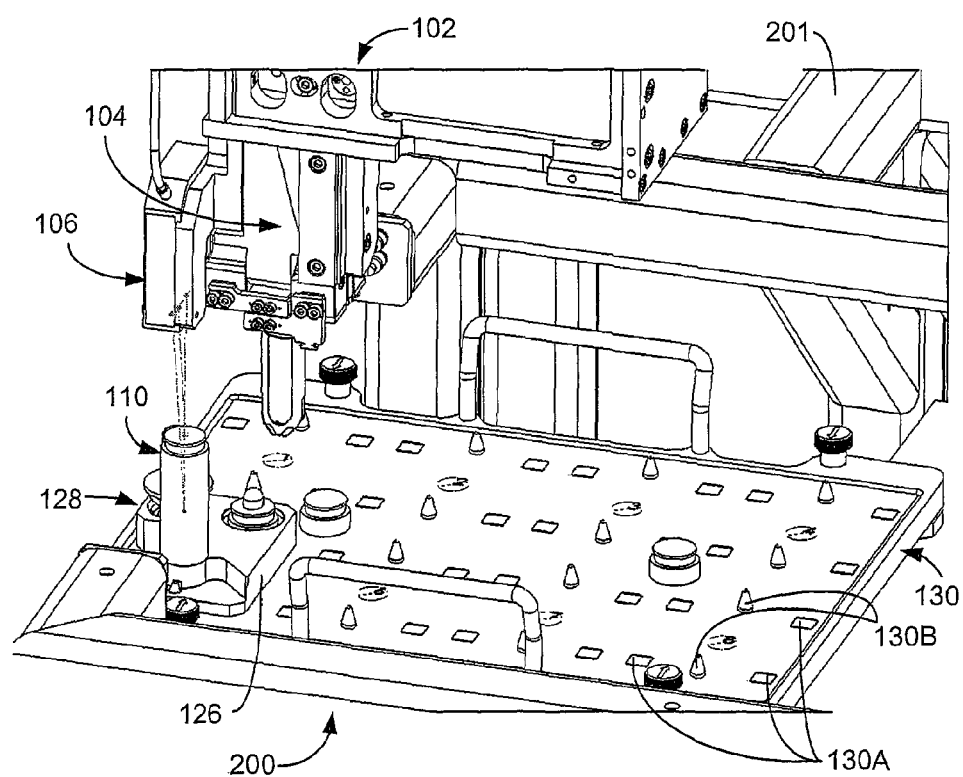
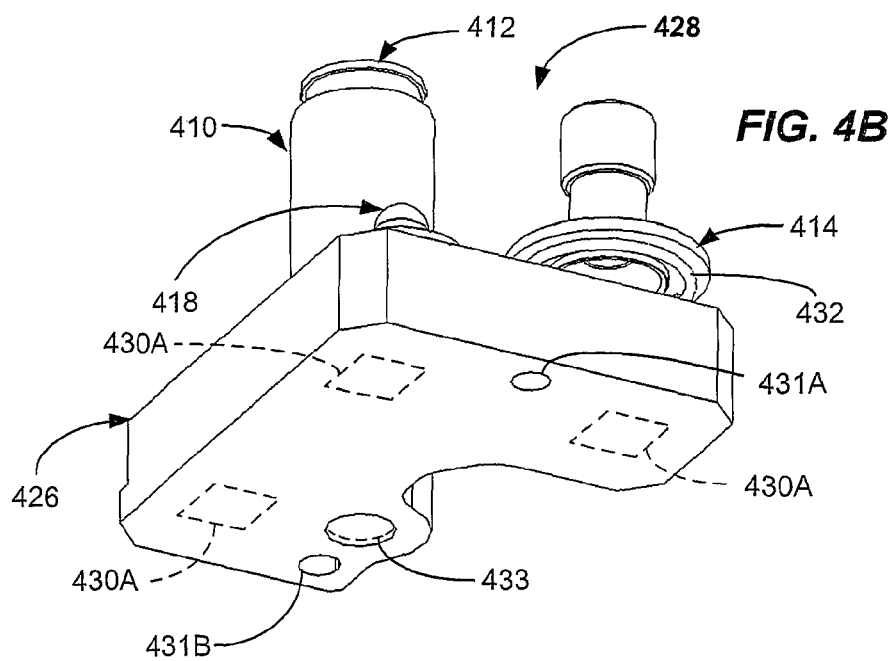
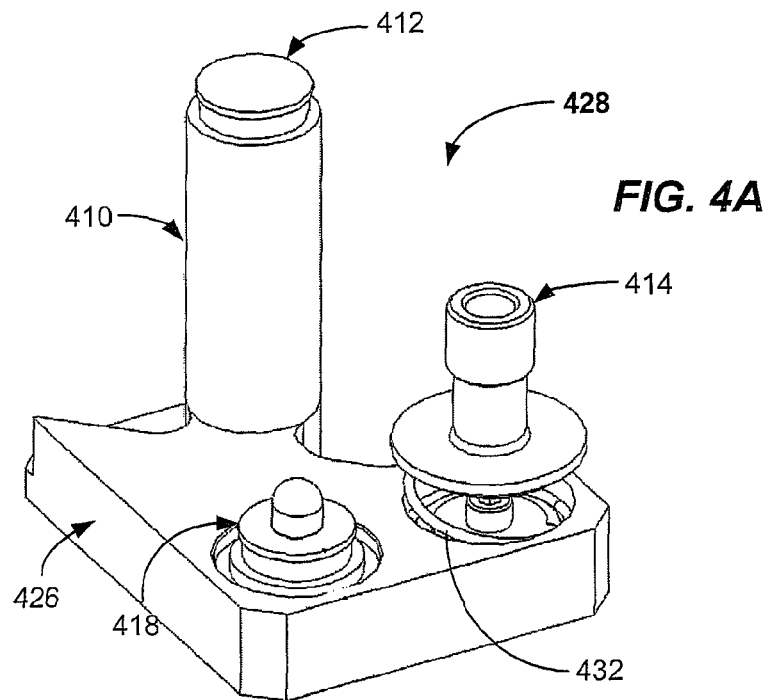
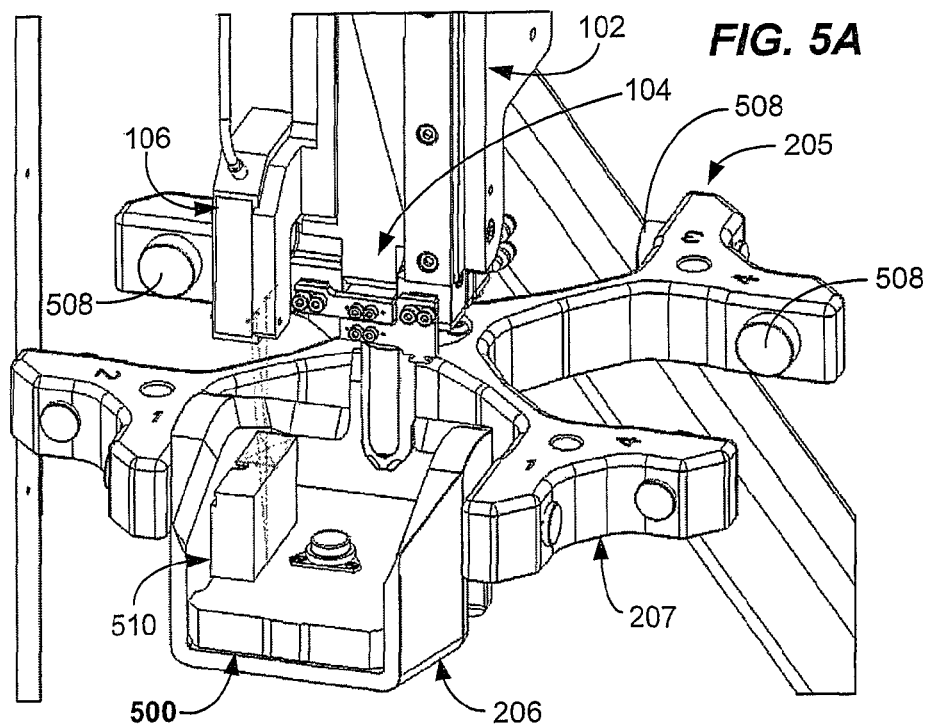
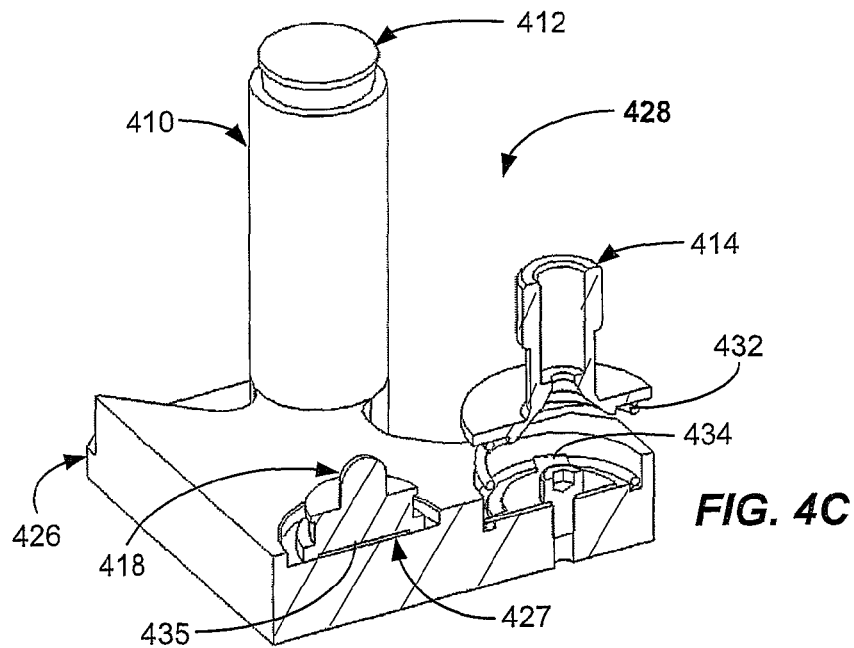
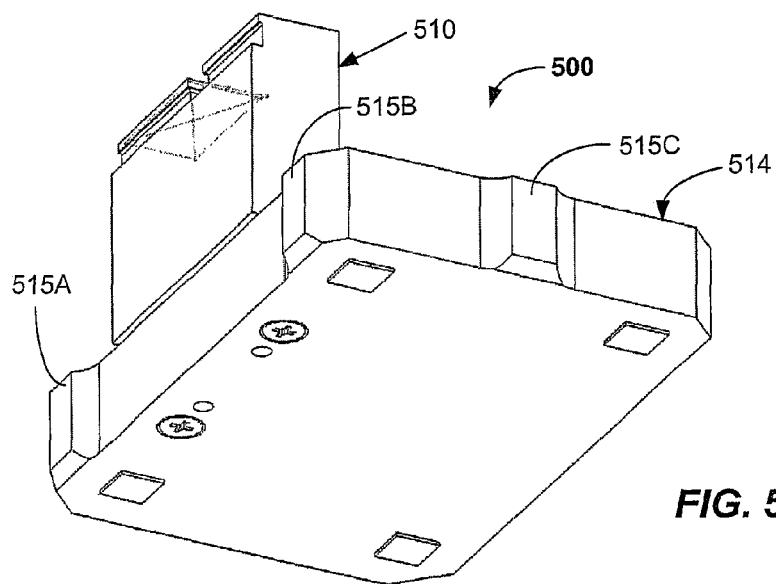
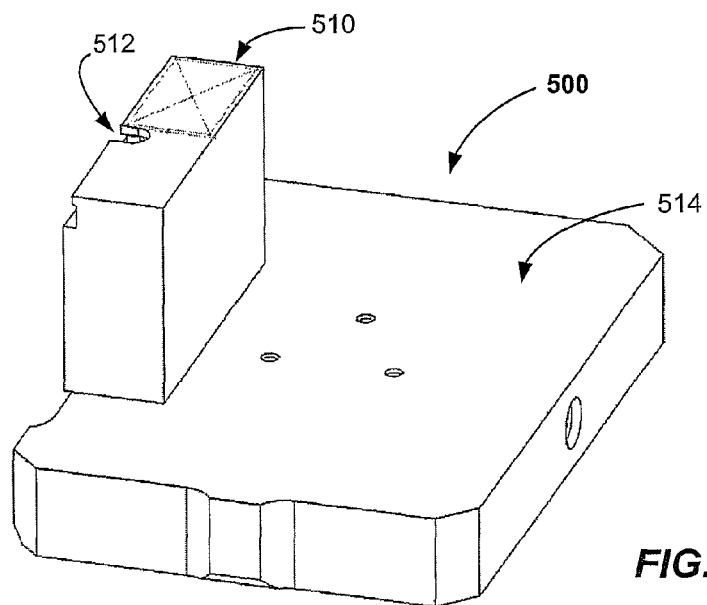
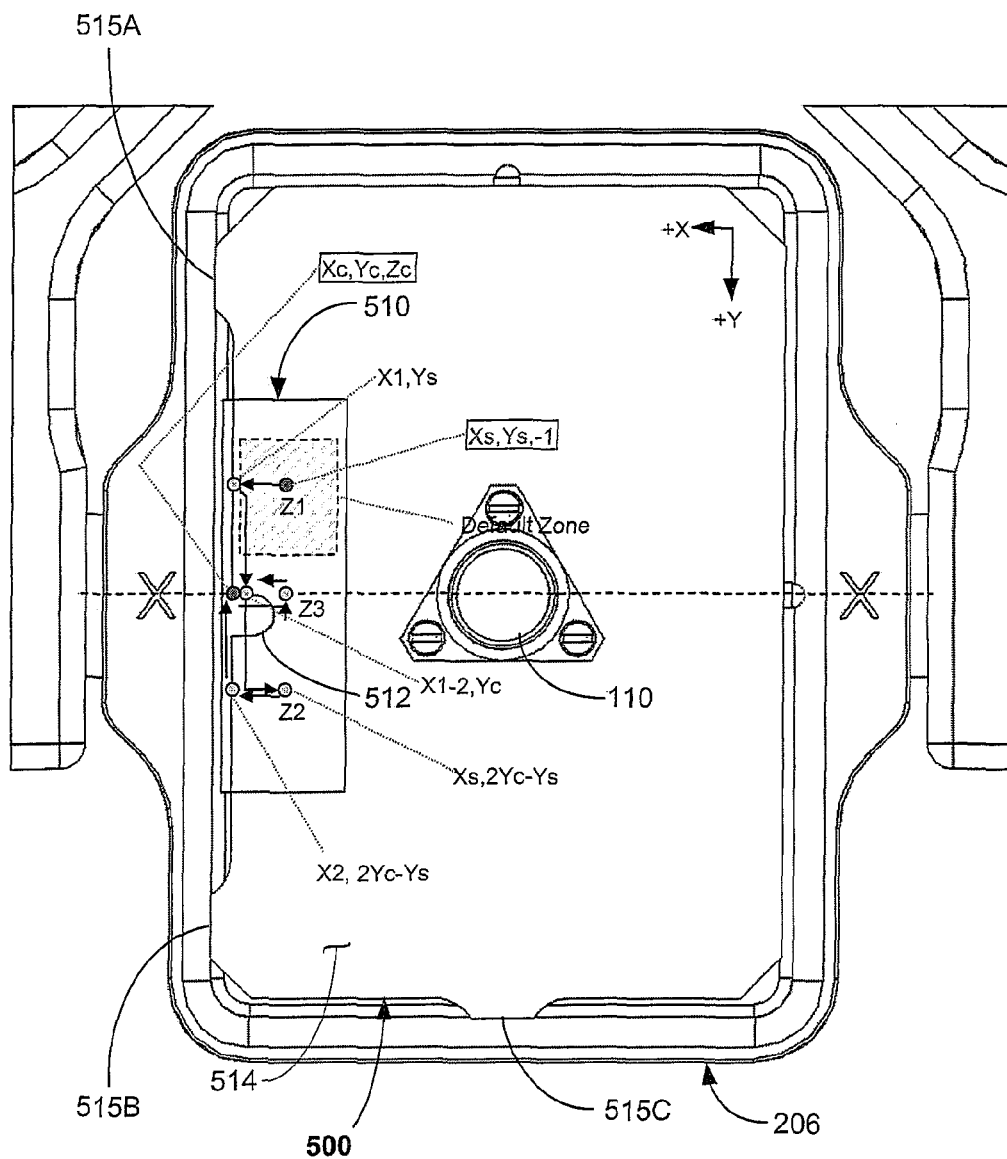


FIG. 3









**FIG. 5D**

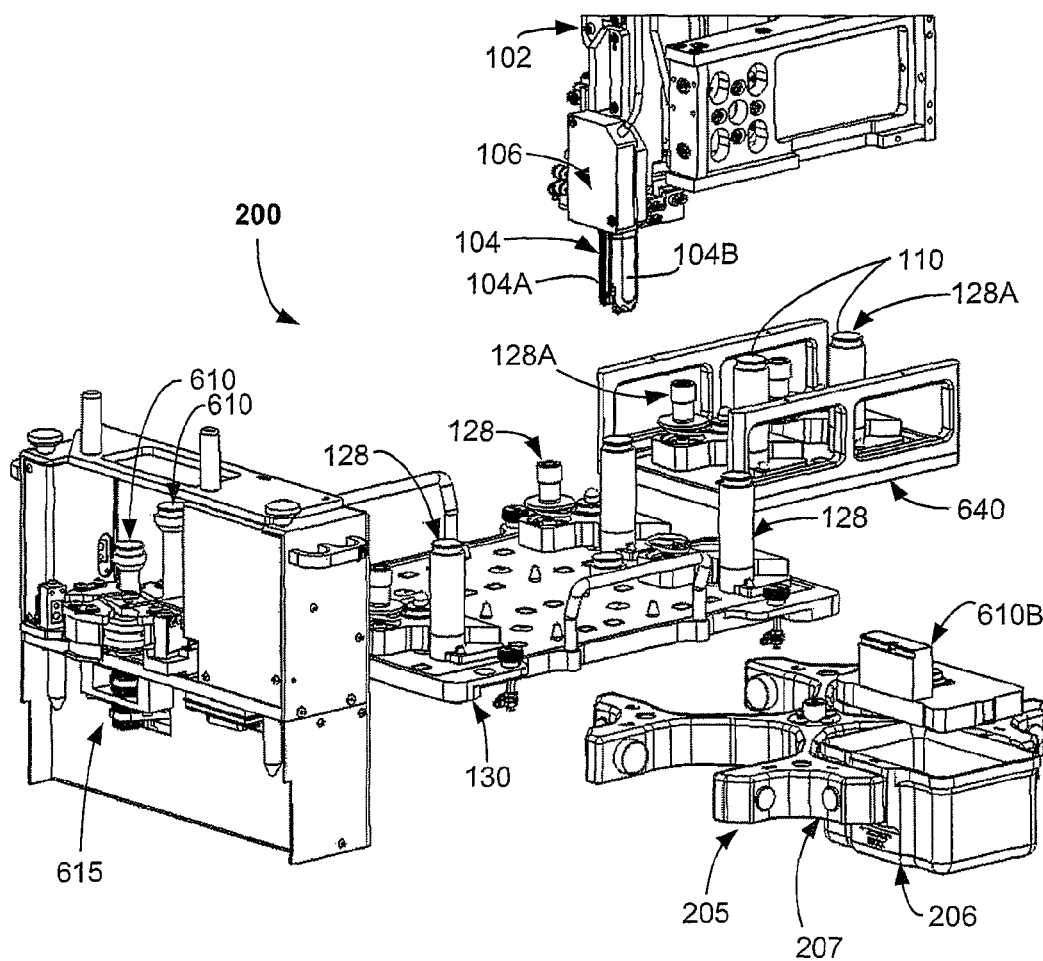
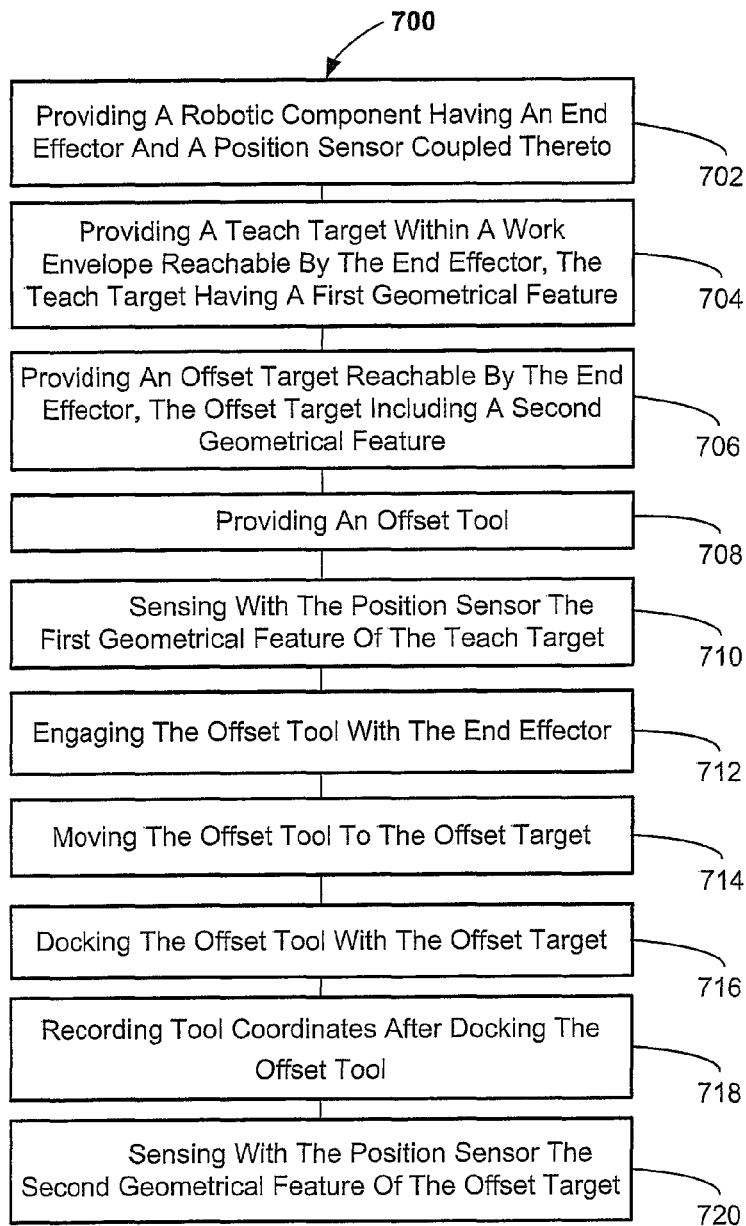


FIG. 6

**FIG. 7**

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# METHODS, SYSTEMS, AND APPARATUS FOR CALIBRATION OF A POSITIONAL OFFSET BETWEEN AN END EFFECTOR AND A POSITION SENSOR

## RELATED APPLICATIONS

The present application claims priority to U.S. Provisional Patent Application Ser. No. 61/357,227, filed Jun. 22, 2010, and entitled "METHODS, SYSTEMS, AND APPARATUS FOR CALIBRATION OF A POSITIONAL OFFSET BETWEEN AN END EFFECTOR AND A POSITION SENSOR," which is hereby incorporated herein by reference in its entirety for all purposes.

## FIELD OF THE INVENTION

The present invention relates generally to systems, apparatus, and methods adapted to calibrate robotic components.

## BACKGROUND OF THE INVENTION

In medical testing and processing, the use of robotics may minimize exposure to, or contact with, bodily fluid samples (otherwise referred to as "specimens") and/or may increase productivity. For example, in some automated testing and processing systems (e.g., clinical analyzers and centrifuges), sample containers (such as test tubes, sample cups, vials, and the like) may be transported to and from sample racks (sometimes referred to as "cassettes") and to and from a testing or processing system. Likewise, sample racks themselves may be transported from one location to another in relationship to the testing or processing system.

Such transportation may be accomplished by the use of an automated mechanism, which may include a robotic component (e.g., a moveable robot arm or gantry arrangement) having a moveable end effector which may have two or more gripper fingers coupled thereto. The end effector may be moved in two or more coordinate directions (e.g., X, Y, and Z). In this way, a sample container (containing a specimen to be tested or processed) or sample rack may be gripped by the end effector, and then moved from one location to another in relationship to the testing or processing system.

Inaccurate positioning of the end effector may cause collisions between the end effector and the sample containers, and/or between the sample container being moved and the equipment or sample rack. In the case where the sample rack is moved, inaccurate positioning of the end effector may cause collisions between the sample rack and the testing or processing system. Additionally, inaccurate calibration may contribute to jarring pick and place operations of the sample container and/or sample rack, which may contribute to unwanted spillage of the specimen. Accordingly, systems, apparatus, and methods that may improve accuracy of positioning of sample containers and sample racks being conveyed to and from testing and processing systems are desired.

## SUMMARY OF THE INVENTION

According to a first aspect, an improved system is provided. The system includes a robot offset calibration system including a robotic component having an end effector and a position sensor coupled thereto, a teach target having a first geometrical feature, an offset tool adapted to be engaged by the end effector, the offset tool including a first docking feature, and an offset target having a second docking feature

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adapted to be engaged by the first docking feature and a second geometrical feature adapted to be sensed by the position sensor.

In a method aspect, an improved method of calibrating in a sample container transfer is provided. The method includes providing a robotic component having an end effector and a position sensor coupled thereto, providing a teach target within a work envelope reachable by the end effector, the teach target having a first geometrical feature, providing an offset target reachable by the end effector, the offset target including a second geometrical feature, providing an offset tool, sensing with the position sensor the first geometrical feature of the teach target, engaging the offset tool with the end effector, moving the offset tool to the offset target, docking the offset tool with the offset target, and sensing with the position sensor the second geometrical feature of the offset target.

In an apparatus aspect, a calibration assisting apparatus is provided. The apparatus includes a base, a teach target mounted on the base and having a first geometrical feature adapted to be sensed by a position sensor, an offset tool mounted on the base and having a first docking feature, and an offset target mounted on the base and having a second docking feature adapted to be engaged by the first docking feature of the offset tool and a second geometrical feature adapted to be sensed by a position sensor.

In another apparatus aspect, a calibration assisting assembly is provided. The assembly includes a tray, a nesting tool coupled to the tray, the nesting tool including a base, a teach target mounted on the base and having a first geometrical feature adapted to be sensed by a position sensor, an offset tool mounted on the base and having a first docking feature, and an offset target mounted on the base and having a second docking feature adapted to be engaged by the first docking feature of the offset tool and a second geometrical feature adapted to be sensed by a position sensor.

Still other aspects, features, and advantages of the present invention may be readily apparent from the following detailed description by illustrating a number of example embodiments and implementations, including the best mode contemplated for carrying out the present invention. The present invention may also be capable of other and different embodiments, and its several details may be modified in various respects, all without departing from the spirit and scope of the present invention. Accordingly, the drawings and descriptions are to be regarded as illustrative in nature, and not as restrictive. The drawings are not necessarily drawn to scale. The invention is to cover all modifications, equivalents, and alternatives falling within the spirit and scope of the invention.

## BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1A is a partially cross sectioned side view illustration of an example of a calibration assisting assembly according to embodiments of the invention.

FIGS. 1B-C are side view graphical depictions that illustrate motion of a position sensor relative to a teach target according to embodiments of the invention.

FIG. 1D is a top view graphical depiction that illustrates motion and positioning of a position sensor relative to a teach target in X-Y coordinates according to embodiments of the invention.

FIG. 1E is a side view depiction of the end effector grasping and picking up an offset tool according to embodiments of the invention.



FIG. 1F is a side view depiction of the end effector docking an offset tool with a moveable offset target according to embodiments of the invention.

FIG. 1G is a side view depiction of the position sensor measuring location coordinates of the offset target according to embodiments of the invention.

FIGS. 1H-1J are partially cross-sectioned side view depictions of the alternative docking features for the offset tool and the offset target according to embodiments of the invention.

FIG. 2A is a perspective view illustration of a testing system including an example calibration assisting assembly having a nesting tool coupled to a tray according to embodiments of the present invention.

FIG. 2B is a perspective view illustration of the testing system of FIG. 2A the example calibration assisting assembly with various centrifuge components removed for clarity according to embodiments of the present invention.

FIG. 2C is a perspective view illustration of the testing system of FIG. 2A including an example robotic apparatus positioned over the nesting tool according to embodiments of the present invention.

FIG. 3 is a partial perspective view illustration of an example calibration assisting assembly having a nesting tool coupled to a tray according to embodiments of the present invention.

FIGS. 4A-4C are perspective views of an example of a nesting tool according to embodiments of the present invention.

FIG. 5A is a perspective partial view of an example calibration block installed in a cradle of a centrifuge according to embodiments of the present invention.

FIGS. 5B-5C are perspective views of the example teach target of FIG. 5A according to embodiments of the present invention.

FIG. 5D is a top view of the example teach target of FIG. 5A according to embodiments of the present invention.

FIG. 6 is a perspective view of an example of a calibration nesting tool installed at multiple locations according to embodiments of the present invention.

FIG. 7 is a flowchart illustrating a method according to embodiments of the present invention.

#### DETAILED DESCRIPTION

In robotic apparatus, such as those used to accomplish robotic pick and place operations, for the aforementioned reasons, achieving precision in the placement of a robotic end effector is desirable. "End effector" as used herein is any member coupled to a robot that is used for robotic operations such as pick and place operations. In some systems, a positional sensor (e.g., a ranging sensor) may be employed with the robotic end effector in the robotic system. In such robotic systems, positional precision to several thousands of an inch or less may be desirable. However, in many instances, tolerance stack-ups from the multitude of connected system components may amount to many thousands, or even tens or hundreds of thousands of an inch. Accordingly, means for appropriately determining an actual positional offset (e.g., in x, y, and z space) between a robotic end effector and a positional sensor in such robotic systems is desired. Furthermore, once calibrated with the appropriate positional offsets, it may be desirable to precisely locate other system components reachable by the robotic apparatus.

In view of the foregoing problems, the present invention provides calibration methods, calibration assisting systems, and calibration assisting apparatus for readily determining an actual (real) positional offset between an end effector and a

position sensor in a robotic system. According to a first aspect, a calibration method includes providing a teach target, an offset tool, and an offset target, which are collectively used to obtain a positional offset between the end effector and the position sensor of the robotic system. According to the method, the position sensor may sense (measure) a first geometrical feature of the teach target so as to obtain first positional information (e.g., X, Y and Z). The offset tool is engaged (e.g., grasped) by the end effector in a known orientation relative to the end effector and moved to a position of the offset target. Once there, the offset tool is docked with the offset target. The docking may involve mating docking features of the offset tool with the offset target. For example, one or more surfaces of the offset tool may be docked with one or more surfaces of the offset target. One or more of the docking surfaces may be inclined relative to a vertical axis (e.g., Z axis). The act of docking may cause the offset target to shift or move slightly in one or more directions (e.g., cause movement in x-y space) in the likely event that some tolerance stack-up is present in the robotic system. In any event, the act of docking positions a centerline of the offset target so that it is coincident with a centerline of the end effector (e.g., in x-y space). A second geometrical feature of the offset target having a known relationship to the offset target's centerline (preferably coincident therewith) and another surface (e.g., a top surface) may then be measured with the position sensor. From the collective measured positional coordinate information from the teach target and offset target, a positional offset between the machine position of the end effector and the actual position sensed by the position sensor may be determined in one or more coordinate directions. This may include determining actual offsets in the X, Y, or Z directions, the X and Y only, X and Z only, X and Y only, and preferably in all three directions (e.g., in X, Y, and Z).

In another aspect, a calibration assisting apparatus is provided. The calibration assisting apparatus, which is referred to herein as a "nesting tool," includes a base, a teach target mounted on the base, the teach target having a first geometrical feature adapted to be sensed by a position sensor; an offset tool mounted on the base and having a first docking feature, and an offset target slidably mounted on the base and having a second docking feature adapted to be engaged by the first docking feature of the offset tool and also having a second geometrical feature adapted to be sensed by the position sensor. In another aspect, the calibration assisting assembly may include a tray onto which the above-described nesting tool is coupled. However, it should be apparent that the nesting tool may be positioned anywhere within the reach of the robotic apparatus. Further, more than one nesting tool may be employed.

In another aspect, a robot offset calibration system is provided. The offset calibration system includes a robotic component having an end effector and a position sensor couple thereto, a teach target having a first geometrical feature, an offset tool adapted to be engaged by the end effector, the offset tool including a first docking feature, and an offset target having a second docking feature adapted to be engaged by the first docking feature and also having a second geometrical feature adapted to be sensed by the position sensor.

These and other aspects and features of the invention will be described with reference to FIGS. 1A-7 herein.

In accordance with a first embodiment of the invention, as best shown in FIG. 1A, a robot offset calibration system 100 is described. The robot offset calibration system 100 is useful for aiding in the calibration of any robotic system, such as those used in automated clinical analyzers, centrifuges, or other processing systems (e.g., bio-fluid specimen processing

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systems). The robot offset calibration system **100** includes a robotic apparatus including a robotic component **102** having an end effector **104** and a position sensor **106** each being coupled thereto. The position sensor **106** may be coupled directly to a portion of the end effector **104** or to a portion of the robotic component (e.g., to a robot arm, boom, or beam), but the location between the end effector **104** and the position sensor **106** is fixed. Likewise, the dimension between the lower terminal ends of the gripper fingers **104A**, **104B** of end effector **104** and the preset far and near ranges of the position sensor **106** is also fixed.

A controller **108** may command the robotic component **102** and attached end effector **104** and position sensor **106** to move in one or more coordinate directions, and preferably two or more or even three directions, but preferably in X, Y, and Z coordinate space, where Y is into and out of the paper in FIG. 1A. Any suitable robotic component **102** may be used, such as a moveable robot arm, boom, or beam having the end effector **104** coupled thereto. In some embodiments, the robotic component **102** may include one or more shoulder, elbow, or wrist elements to accomplish three-dimensional motion of the end effector **104**.

In other embodiments, such as in the processing system **200** of FIG. 2A-2C, the robotic component **102** may be mounted to a frame **201** and may include a moveable gantry arrangement with the end effector **104** which is mounted to a boom **203**. The boom **203** may be moveable (e.g., in the Z direction) on a suitable track or guide. Furthermore, the boom **203** (and the end effector **104**) may be moveable along a track or guide in one or more additional directions (e.g., the X and/or Y directions). In the depicted embodiment, movement of the end effector **104** is provided in the X, Y, and Z coordinate directions. The means for moving the robotic component **102** may include any suitable conventional motion-producing mechanism, such as a stepper motor, servo motor, pneumatic or hydraulic motor, electric motor, etc. Furthermore, drive systems including chains, guides, pulleys and belt arrangements, gear or worm drives or other conventional drive components may be utilized to cause the motion of the robotic component **102** and coupled end effector **104**. Other types of robot apparatus may be employed.

The processing system **200** depicted is an automated centrifuge system adapted to separate various components of specimens provided therein. In particular, the centrifuge **205** may be a Hettich centrifuge available from Hettich Centrifuges of Beverly, Mass., that is adapted to receive sample racks (otherwise referred to as "sample cassettes") in a bucket **206** pivotally mounted to a yolk **207** of the centrifuge **205** (See FIG. 2A-2C and FIG. 5A). Only the bucket **206** and yolk **207** of the centrifuge **205** are shown in FIG. 2B and FIG. 5A for clarity. A tray **130** of the processing system **200** may be coupled to a weighing mechanism **209** (e.g., a weight scale) adapted to measure the weight of each of the cassettes, etc. resting on the tray **130**. The nesting tool **128** is also shown mounted on the tray **130**. Other processing components may be attached to the frame **201**, but are not shown for clarity. Although the depicted examples are directed at a processing system **200** that is an automated centrifuge system, it should be understood that the present invention method, calibration assisting apparatus, system, and nesting tool have utility for other types of automated processing systems as well as automated testing systems.

Again referring to FIG. 1A, the opposed gripper fingers **104A**, **104B** (only one finger **104A** shown in FIG. 2C) may be driven to open and close along any suitable direction in the X-Y plane e.g., in the X or Y direction) by a suitable end effector drive apparatus, such as a servo motor or the like. For

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example, a pneumatic or hydraulic servo motor or electric motor may be used. Any suitable mechanism for causing gripping action of the fingers **104A**, **104B** may be used. Furthermore, although two fingers are shown, the present invention is equally applicable to end effectors having more than two fingers or grippers.

Again referring to FIG. 1A, the robot offset calibration system **100** includes a teach target **110**, an offset tool **114**, and an offset target **118**. The teach target **110**, offset tool **114**, and offset target **118** may be mounted on a common base **126** and may make up the components of a nesting tool **128**. The nesting tool **128** may be placed on the processing system **200** (FIGS. 2A-20) at any location within the reach of the robotic component **102** and may be used to assist in a determination (calibration) of a positional offset between the end effector **104** and the position sensor **106** of the robot offset calibration system **100**.

In the depicted embodiment, the teach target **110** is a generally cylindrical post extending upwardly from the base **126** of the nesting tool **128** and includes a first geometrical feature **112** formed thereon. The teach target **110** may be fastened to the base **126** by any suitable means, such as screws, bolts, press fit, adhesive, brazing, welding, or other suitable fastening system. The first geometrical feature **112** may be a disc, a rectangle, a square, or any other shaped geometric feature including edges that may be located by the position sensor **106** in at least one direction, but preferably at least in the X and Y directions, and preferably in the X, Y, and Z directions. The first geometrical feature **112** may include a first planar surface **112A** that lies substantially in the X-Y plane and may include two or more stepped edge surfaces at opposite sides thereof. The first planar surface **112A** is adapted to be sensed by the position sensor **106** in the vertical (Z direction). The first planar surface **112A** may be vertically offset from, and different (e.g., smaller) in lateral overall outside dimension than, a second planar surface **112B** of the teach target **110** lying at a different vertical level (e.g., vertically lower) than the first planar surface **112A**, thereby providing vertically-stepped surfaces. The measured surfaces **112A**, **112B** and edges should be precision machined such that their location on the nesting tool **128** is precisely known.

The offset tool **114** may be adapted to be engaged by the end effector **104** (e.g., by gripper fingers **104A**, **104B**). The offset tool **114** may include a first docking feature **116**, which is adapted to be engaged with a second docking feature **120** of the offset target **118**. In some embodiments, the first docking feature **116** and the second docking feature **120** may include engaging surfaces (e.g., one or more inclined surfaces) to be described more fully below. The offset tool **114** may include a pilot **114A** extending vertically in the Z direction from the location of the first docking feature **116** and a shelf **114B**, which may extend laterally in the X-Y plane, for example. The shelf **114B** is adapted to be contacted by the end effector **104** when the end effector **104** grasps the offset tool **114**. In particular, the fingers **104A**, **104B** are placed in vertical contact with an upper surface of the shelf **114B** as the offset tool **114** is grasped (See FIG. 1E). The offset tool **114** may further include a positioning feature **114C**, such as a centering pilot on a lower surface, to roughly position the offset tool **114** relative to the base **126**. In some embodiments, the offset tool **114** is stationed on a compliant member **132** of the nesting tool **128**. This positions the offset tool **114** relative to the base **126** so that the offset tool **114** may be located and grasped by the end effector **104**. Other types of centering features may be used.

The compliant member **132** may be any suitable spring member, such as a helical or coil spring, wave spring, leaf

spring, volute spring, Bellville spring, air spring, etc. The compliant member **132** may be suitably mounted so that movement relative to the base **126** is limited. Providing a compliant member **132** allows for ease of grasping the offset tool **114** while minimizing load spikes as the ends of fingers **104A**, **104B** contact the shelf **114B**.

The offset target **118** may also be mounted on the base **126**. The offset target **118** may include a second geometrical feature **122** adapted and oriented to be sensed by the position sensor **106**. In some embodiments, the first and second geometrical features **112**, **122** may include substantially similar features. For example, they may both include circular discs of substantially the same diameter formed or provided thereon. Furthermore, the second geometrical feature **122** may include first and second offset (e.g., planar) surfaces **122A**, **122B**, as described above for the teach target **110**.

The docking features **116**, **120** may be any suitable geometric features including engaging surfaces, which allow for centering of the offset target **118** in the X, Y, or X and Y directions relative to the end effector **104**. In the depicted embodiment, the first docking feature **116** comprises a conical (inclined) surface formed on an underside of the offset tool **114**. However, the inclined surface may be a compound inclined surface (See FIG. 4C). For example, the first docking feature **116** may include multiple intersecting conical surfaces oriented at different cone angles or arcuate (curved) surfaces. The second docking feature **120** of the offset target **118** may also include inclined surfaces, which are adapted to interface with the engagement surfaces of the first docking feature **116**. For example, the second docking feature **120** may be formed on an upper portion of the offset target **118**.

In the depicted embodiment of FIGS. 1A and 1F, the second docking feature **120** includes an inclined surface which comprises a curved surface (e.g., a spherical surface) and is precisely centered relative to the second geometrical feature **122** (e.g., a disc). The portion of the spherical surface that contacts the first docking feature **116** is inclined relative to a vertical axis (Z axis). However, a conical surface or other inclined or curved surface shape may be employed as the second docking feature **120**. Optionally, as is shown in FIGS. 1H-1J, the docking features **116**, **120** of the offset tool **114** and the offset target **118A**, respectively, of FIGS. 1A and 1F may be reversed. For example, as shown in FIGS. 1H-1J, an extending (convex) feature **116A** may be provided on the offset tool **114A** and a receiving (concave) feature **120A** may be provided on the offset target **118A**. Any combination of interfacing concave and convex members may be employed as the first and second docking features **116A**, **120A**. In some embodiments, only one of the docking features may include an inclined surface (See FIG. 1J), although it is preferred that both include an inclined surface. The docking features **116A**, **120A** may both include conical surfaces as shown in FIG. 1I, but matching such features may introduce later shift errors. Thus, such matched features should only be employed where a relatively lower level of accuracy may be tolerated. Any suitable geometry that allows for centering of the offset target **118** in the X and/or Y coordinate directions may be used. However, a configuration as shown in FIG. 1H including docking features **116A**, **120A** (or **116**, **120** as shown in FIG. 1H) including a spherical surface on one member and a conical surface on the other provides excellent location precision.

The offset target **118** may include a smooth planar lower surface **118C**, which engages with a smooth planar surface of the base **126**. The act of clocking as shown in FIG. 1F aligns (moves) the offset target centerline **118D** with the centerline **104C** of the end effector **104** when the end effector **104** is

located at a predetermined second nominal location of the offset target **118** in X, Y space.

In the depicted embodiment of FIG. 1A-1F, the position sensor **106** is a laser ranging sensor, which is adapted to emit multiple intersecting laser beams **106A** towards a target (only one beam shown for clarity). In the depicted embodiment, the position sensor **106** may be operable to sense a position of an article (e.g., a cassette, specimen container or vial, test tube, cuvette, tool, etc.) to be grasped, or a position of a feature (e.g., a hole, slot, pilot, pin, edge, etc.) at a location where the article is to be placed. The position sensor **106** may be any suitable position sensor adapted to determine a position in one or more coordinate directions, but a laser ranging sensor is preferred. A class 2, red, laser ranging sensor available from Banner Engineering of Minneapolis, Minn. was found to be effective. Other types of laser sensors may be used depending on the number of coordinate dimensions desired to be measured. Other types of position sensors (e.g., contact type) may be used as well.

In the present calibration assisting system and method, the position sensor **106** is adapted to sense the first geometrical feature **112**. For example, as shown in FIG. 1A, the position sensor **106** may be moved from a nominal at rest position at (X0, Y0, Z0) to a known nominal position above the teach target **110**. The teach target **110** may be provided, as part of the calibration process, at a nominally known position in X, Y, Z space so that the controller **108** may command the movement of the position sensor **106** to that nominal location in space. For example, the teach target **110** may be provided at any known position within the reach (working envelope) of the robotic component **102**. In some embodiments, the nesting tool **128** may be placed manually by an operator at the predefined location and orientation in X, Y, Z space, or even by grasping the nesting tool **128** with the end effector **104** and placing it on positioning elements (e.g., pins) on a portion of the processing system **200**.

In some embodiments, as best shown in FIG. 3, the teach target **110** may be coupled to the base **126** of the nesting tool **128**, which may then be coupled to a tray **130** of a processing system **200**. The tray **130** may be removable from the frame **201** of the processing system **200**. The approximate nominal position of the teach target **110** is known because the teach target **110** is provided in a fixed position and orientation relative to the nesting tool **128**, and the base **126** of the nesting tool **128** is provided in a nominally known position on the tray **130** provided on the frame **201** within reach of the robotic component **102**. For example, as shown in FIG. 1A and FIG. 3, the base **126** may rest on one or more pads **130A** (preferably three pads) formed on the tray **130** or on the nesting tool **128**. Two or more tray projections **130B** (e.g., tapered pins) extending from the tray **130** may couple with like tapered holes, or a hole and slot (shown dotted in FIG. 1A) to further aid in positively positioning the nesting tool **128** relative to the tray **130**. Optionally, pins may be formed on the nesting tool **128** and may be received in holes (or a hole and a slot) formed in the tray **130**. Thus, it should be apparent that the nesting tool **128** is configured to be moveable, but may be precisely located at one or more desirable locations within the reach of the robotic component **102** and end effector **104**. A plurality of sample racks (not shown) including specimen containers may be received on the tray **130** for processing.

Another embodiment of the nesting tool **428** including the teach target **410**, offset tool **414**, and offset target **418** mounted on a common base **426** is shown in FIGS. 4A-4C. As depicted, the base **426** includes a generally L-shape configuration including a first branch and a second branch arranged approximately perpendicularly to one another such that the

aforementioned pads **130A** of the tray **130** will contact the base **426** at three locations (shown dotted, thereby providing stability. A hole **431A** and a slot **431B** (shown only slightly elongated) may be formed in the underside of the base **426** and are adapted to receive and locate on the pins **130B** of the tray **130** (see FIG. 3). A threaded portion (not shown) of the teach target **410** may be received in a threaded hole **433** provided in the base **426**. The teach target **410**, offset tool **414**, offset target **418**, and base **426** may each be manufactured from a suitable rigid material such as, e.g., stainless tool steel. FIG. 4C illustrates the nesting tool **428** with the offset tool **414** and offset target **418** shown cross sectioned. As can be seen, the offset tool **414** may be stationed on a compliant member **432** (e.g., a coil spring) and the compliant member **432** may be retained relative to the base **426** by a spring retainer **434**. As shown in FIG. 4C, a portion **435** (e.g., a central underside portion) of the offset target **418** may be recessed slightly so that it does not contact the recess **427**. Accordingly, a friction force to slide the offset target **418** in the recess **427** of the base **426** may be minimized.

FIGS. 5A-5C illustrate a teach target assembly **500** including a teach target **510** mountable in a bucket **206** of a centrifuge **205**. The bucket **206** is rotationally mounted for pivotal motion on a yolk **207**. When a sample rack containing specimen containers (not shown) is received in the bucket **206** and the centrifuge **205** is spun (rotated) to operating speed, the bucket **206** will be thrown outwardly due to centrifugal force and pivot about the respective mounting pivots **508** (shown for bucket mounting locations **2**, **3** and **4**). Once the robot offset is properly calibrated using the method discussed herein, the teach target **510** may be employed to precisely locate the bucket **206** relative to the end effector **104**, such that transfers of the sample racks to the bucket **206** may be carried out with relative precision. The teach target **510** may be sensed with the position sensor **106** at another location within the reach of the robotic component **102**, such as at another bucket **206** (only one bucket shown) or another location.

Top and bottom views, respectively, of the teach target assembly **500** are shown in FIGS. 5B and 5C. The teach target assembly **500** may include a locator base **514** having the teach target **510** mounted thereto. Mounting may be by suitable fastening means (e.g., screws). The locator base **514** may include locator points **515A-515C** adapted to contact precisely formed portions of the bucket **206** such that the locator base **514** is precisely positioned in a bottom of the bucket **206** (See FIG. 5D). Once positioned, the controller **108** (FIG. 1A) may cause the robotic component **102** to move to position the position sensor **106** at the nominal location of the teach target **510**. As shown in FIG. 5D, a routine is then carried out to locate a geometrical feature **512** on the teach target **510**. The routine may be as follows:

Start above bucket **206**

Move down until position sensor **106** (e.g., laser ranging sensor) turns ON (at Far range of sensor) at Z1

Record Z1 reading

Move down 1 mm until laser turns OFF (at near range of sensor)

Move in +X direction until position sensor **106** turns ON to find 1<sup>st</sup> vertical edge Xs, Ys

Move 2 mm in -X (laser OFF) and in +Y until laser turns ON

Find 1<sup>st</sup> horizontal edge at X1-2, Yc

Move in +Y to 2Yc-Ys (laser OFF) and in -X to Xs

Find, 2<sup>nd</sup> Z at Z2

Move 1 mm down to turn laser OFF.

Move in +X until laser turns ON.

Find 2<sup>nd</sup> vertical edge X2, 2Yc-Ys

Since  $X_c = (X_1 + X_2)/2$  and  $Z_c = (Z_1 + Z_2)/2$

Teach target corner is found: Xc, Yc, Zc

Using the above method, the exact positional location of the geometrical feature **512** in X, Y, Z space may be found. Accordingly, the location of geometrical features of the bucket **206** may be precisely determined. It should be understood that one or more additional teach targets (e.g., teach target **110**) may be used on the teach target assembly **500**, or on any other component of the processing system **200** within the reach of the position sensor **106** to aid in precisely locating that component.

An embodiment of an example method of the invention will now be described with reference to FIGS. 1A-1G. According to the method, and as shown in FIG. 1A, the position sensor **106** is lowered in the -Z direction to sense the position of the first surface **112A** of the first geometrical feature **112** in the Z direction. If a laser ranging sensor is used as the position sensor **106**, the laser ranging sensor may provide an output signal in signal line **106** when a distance (d) between the position sensor **106** and the first surface **112A** is less than or equal to a predetermined value (far range value). Accordingly, as the laser ranging sensor is moved in the -Z direction towards the approximate center of the first surface **112A** of the first geometrical feature **112**, a signal will be provided in line **106B** as the predetermined distance (d) is reached at a preset far end range of the laser ranging sensor. Memory resident in the controller **108** may record the Z position coordinate when the signal in signal line **106B** is received thereat. Thereafter, the position sensor **106** is moved further in the -Z direction until the laser ranging sensor is turned off (at a near end of the laser's preset range).

Now, the controller **108** may cause the robotic component **102** and coupled position sensor **106** to move in the -X direction along a path **106X** until a first stepped edge of the first geometrical feature **112** on a first side is found, as shown in FIGS. 1B and 1D. Finding the first stepped edge occurs when the signal in signal line **106B** again appears because the distance (d1) to the second surface **112B** is now again within the range of the laser ranging sensor when the beam **106A** projects off of the edge of first surface **112A** and onto the second surface **112B** of the teach target **110** at the stepped edge location. Similarly, the controller **108** may cause the robotic component **102** and coupled position sensor **106** to move in the +X direction along path **106X** until a second stepped edge on the other side of the first surface **112A** of the first geometrical feature **112** is found, as shown in FIGS. 1C and 1D. Finding the second stepped edge occurs when the signal again appears because the distance (d2) is within the preset range of the laser range sensor. Each of these stepped edge location readings may be recorded in memory of the controller **108**. The center position of the first geometrical feature **112** in the X direction may be determined by subtracting half the difference between the first and second stepped edge X readings recorded in memory of the controller **108**. This may be repeated again for further accuracy once the first determination is made.

Similar determinations may be made in the Y direction by locating the stepped edges of the first surface **112A** in the +Y and -Y directions along the path **106Y**, recording the +Y and -Y coordinates in memory, and subtracting half the difference between the +Y and -Y coordinate measurements to obtain a location of the center of the teach target **110** in the Y direction. These readings may be recorded in memory of the controller **108**. Once known, the Y determination may be measured again for improved accuracy. Accordingly, the X, Y

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dimensions of the centerline of the teach target **110**, as well as the location of the first surface **112A** in the Z direction may be accurately determined.

Now referring to FIG. 1E, the end effector **104** may be moved via a command from the controller **108** such that a centerline **104C** of the end effector **104** is moved to be approximately positioned above the nominally known position of the offset tool **114** stationed on the compliant member **132**. The end effector **104** is then lowered in an opened condition until the end of the fingers **104A**, **104B** contact an upper surface (shelf) **114B** of the offset tool **114**. The end effector **104** is further lowered to slightly compress the compliant member **132** onto which the offset tool **114** rests and is stationed for access. Now the gripper fingers **104A**, **104B** may be moved inwardly towards each other to grasp the offset tool **114** by the pilot **114A**, as is shown in FIG. 1E. In this orientation, the offset tool **114** is precisely positioned relative to the centerline **104C** and the tips of the fingers **104A**, **104F** of the end effector **104** are precisely located relative to the first docking feature **116**.

As shown in FIG. 1F, the offset tool **114** is now moved by the end effector **104** via a command from the controller **108** to a nominally known position of the offset target **118**. The offset target **118** may be approximately located and centered in the X-Y directions in a cylindrical recess **127** formed in a base **126** of the nesting tool **128**. As the docking takes place via moving the end effector **104** in the -Z direction, the interaction of the docking features **116**, **120** may cause the slideable offset target **118** to slide and shift in the X and/or Y direction along the surface of the recess **127** and become repositioned at a new location in the recess **127**. The offset tool **114** may then be carefully removed along the -Z direction so as to not disturb the location of the offset target **118**, and may be returned to its station on the compliant member **132** (See FIG. 1E).

Next, as shown in FIG. 1G, the controller **108** causes the robotic component **102** to move the position sensor **106** to above the nominal position of the offset target **118** in X-Y space. As with the teach target **110**, the Z position of the top (first off set) surface **122A** in the Z direction may be determined by lowering the position sensor **106** until the far end of the range of the laser range sensor is reached. This Z reading may be recorded in memory in the controller **108**. The routine then searches for the respective stepped edges of the second geometrical feature **122** in the X and Y directions in the same manner as described above for the first geometrical feature **112** of the teach target **110**. The only difference is that because the second docking feature **120** is included atop the second geometrical feature **122**, the searching must commence on the first offset surface **122A** at a position offset from the center of second geometrical feature **122**. From this, the X and Y center coordinates of the offset target **118** may be readily determined based upon the respective differences between the +X and -X and +Y and -Y readings. These X and Y center values may be stored in memory.

From these X, Y, and Z values determined based upon the readings taken and stored for the teach target **110** and those taken and stored for the offset target **118**, an exact positional offset in one or more of the coordinate directions (X, Y, and/or Z) may be determined. In particular, the positional offset between the end effector centerline **104C** and the beam **106A** of the position sensor **106** in the X and Y directions may be determined. Likewise, a positional offset between the tips of the fingers **104A**, **104B** and the Z preset ranges measured by the position sensor **106** may be determined. As such, an internal positioning for the robotic component **102** may be

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nullified at (0, 0, 0) to reflect the offsets such that positioning of the end effector **104** will be true within the reach of the robotic component **102**.

Again referring to FIG. 3, the nesting tool **128** may be positioned on the tray **130** at any desired position to obtain the offset position information. For example, the nesting tool **128** is shown positioned at a farthest distance from the robot apparatus zero position on the tray **130**. Once the offset information is obtained, the same nesting tool **128** may be repositioned at another location on the tray **130** or on another system component about which it is desired to obtain positional information. It should then be understood that in some embodiments, multiple nesting tools may be employed in the system for determining positional information about the exact location of other system components. For example, FIG. 6 illustrates placing multiple nesting tools **128** onto various locations on the tray **130**.

As shown in FIG. 6, additional nesting tools **128A** may be placed on an inflow/outflow area **640** where cassettes and/or specimen containers, vials, test tubes, etc. may be staged. Optionally, inflow/outflow area **640** may simply be a storage area for the nesting tools **128A** to be accessed by the end effector **104**. For example, the end effector fingers **104A**, **104B** may grasp a post of the teach target **110** and transport one or more of the nesting tools **128A** to any location in the processing system **200** that is within the reach of the robotic component **102**. Additional teach targets **610** may be provided on various other system components for which positional location in X, Y, and/or Z space are desired. For example, teach targets **610** may be provided in a feeder **615**. The feeder **615** may be a tool feeder with a rotatable magazine where various tools may be accessed by the end effector **104** as needed. Optionally, the feeder **615** may function to feed specimens into the processing system. Teach targets **610** having different configurations than that of the teach target **110** of the nesting tool **128** may be employed. For example, a teach target **610B** may be used to calibrate the location of a bucket **206** mounted in a yolk **207** of a centrifuge apparatus **205** as previously described (only the yolk **207**, bucket **206**, and teach target **610B** shown). The teach target **610B** is shown elevated above the bucket **206**, but is received in close registry in the bottom of the bucket **206** during location calibration.

The operation of the present invention method of providing an offset between an end effector **104** and a position sensor **106** in a robot offset calibration system **100** will now be described in more detail with reference to FIG. 7. The method **700** includes, in **702**, providing a robotic component having an end effector and a position sensor coupled thereto, and providing in **704** a teach target (e.g., **110**) within a work envelope reachable by the end effector (e.g., **104**), the teach target having a first geometrical feature (e.g., **112**). The method **700** further includes, in **706**, providing an offset target (e.g., **118**) reachable by the end effector, the offset target including a second geometrical feature (e.g., **122**); providing an offset tool (e.g., **114**) in **708**; and sensing with the position sensor (e.g., **106**) the first geometrical feature of the teach target in **710**. The method **700** further includes engaging the offset tool (e.g., **114**) with the end effector (e.g., **104**) in **712**; moving the offset tool (e.g., **114**) to the offset target (e.g., **118**) in **714**; and docking the offset tool (e.g., **114**) with the offset target (e.g., **118**) in **716**. The method **700** may then record the tool coordinates after docking the offset tool (e.g., **118**) in **718**; and sense with the position sensor (e.g., **106**) the second geometrical feature (e.g., **122**) of the offset target (e.g., **118**) in **720**.

While the invention is susceptible to various modifications and alternative forms, specific system and apparatus embodi-

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ments and methods thereof have been shown by way of example in the drawings and are described in detail herein. It should be understood, however, that it is not intended to limit the invention to the particular systems, apparatus, or methods disclosed but, to the contrary, the intention is to cover all modifications, equivalents, and alternatives falling within the spirit and scope of the invention.

What is claimed is:

1. A method of providing a positional offset, comprising:  
 providing a robotic component having an end effector and  
 a position sensor coupled thereto;  
 providing a teach target within a work envelope reachable  
 by the end effector, the teach target having a first geo-  
 metrical feature;  
 providing an offset target reachable by the end effector, the  
 offset target including a second geometrical feature;  
 providing an offset tool;  
 sensing with the position sensor the first geometrical fea-  
 ture of the teach target;  
 engaging the offset tool with the end effector;  
 moving the offset tool to the offset target;  
 docking the offset tool with the offset target;  
 recording tool coordinates after docking the offset tool;  
 sensing with the position sensor the second geometrical  
 feature of the offset target; and

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determining an offset between the position sensor and the  
 end effector based upon the one or more coordinates of  
 each of the first geometrical feature and the second geo-  
 metrical feature.

2. The method of claim 1, further comprising recording one  
 or more coordinates of the first geometrical feature sensed by  
 the position sensor.

3. The method of claim 1, further comprising recording one  
 or more coordinates of the second geometrical feature sensed  
 by the position sensor.

4. The method of claim 1, further comprising gripping the  
 offset tool with gripper fingers of the end effector.

5. The method of claim 1, wherein docking moves a loca-  
 tion of the offset target in one or more directions.

6. The method of claim 1, wherein engaging the offset tool  
 with the end effector involves compressing a compliant mem-  
 ber on which the offset tool rests.

7. The method of claim 1, further comprising mounting the  
 teach target, the offset tool, and the offset target onto a com-  
 mon base.

8. The method of claim 1, further comprising sensing  
 another teach target with the position sensor at another loca-  
 tion within the reach of the robotic component.

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